TODAY

-- Chap 11, Atomic Nature of Matter

<u>The atomic hypothesis:</u> *(dates back to Democritus, 460-371 BC)*

All things are made of atoms – little particles that move around in perpetual motion, attracting each other when they are a little distance apart, but repelling upon being squeezed into one another.

If, in some cataclysm, all scientific knowledge were to be destroyed, and only one sentence could be passed on to the next generation of creatures, what statement conveys the most information in the fewest words? The atomic hypothesis.

Richard Feynman, 1918-1988

<u>Note:</u> the idea of matter consisting ultimately of indivisible units dates back to 5th BC, but really only established with Einstein in 1905.

Crucial observation: Brownian motion of botanist Robert Brown, 1827.

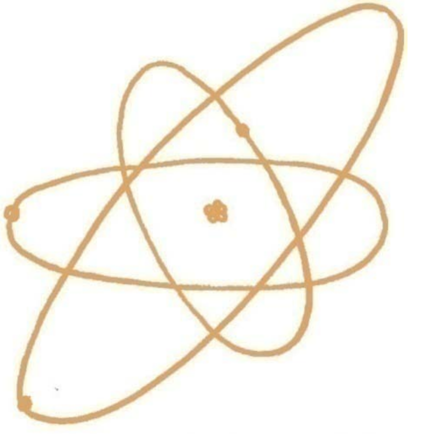
The elements

- Atoms make up all the matter around us, but there are only 118 distinct types of atoms (to date). These are called **elements**.
- The elements combine in an infinite # of different ways in order to yield huge variety of substances.
- Actually, only 88 of the 118 discovered, are found naturally. Others are unstable, and made in nuclear reactors.

- Atom consists of some number of **protons** and **neutrons**, bound together in a nucleus, surrounded by a cloud of **electrons**.
- Simple model: electrons orbit nucleus like a tiny version of planets around the sun.

This is a very simplified model, but ok for many purposes.

Most of the volume is empty.



More about atoms

- **Simplest element** is hydrogen: one proton, no neutrons, one electron (see more later). First element to form after the Big Bang.
- All other (naturally-occurring) elements were formed by thermonuclear fusion in (large) stars, and are remnants of stars that previously exploded.

- Most common elements on earth: hydrogen (H), carbon (C), oxygen (O), nitrogen (N).

"chemical symbols"

- **Atoms are tiny!** Ratio of diameters of atom : apple equals that of apple : earth

- **Numerous**: in 1g of water, there are 10^{23} atoms !

More on atoms continued…

- **Continually recycled:**

Eg. Many atoms in your body are nearly as old as universe itself.

Eg. When you breathe in, some atoms inhaled become part of your body; later will be part of someone else’s body, or a plant, or a building…

Eg. Each breath you breathe, contains atoms that were once part of everyone who ever lived!

- **Constantly moving:**

Eg. Drop of ink in water, rapidly spreads throughout water.

In atmosphere, simple molecules move at 10 x the speed of sound, i.e. 3000 m/s!! Random directions (diffusion)

Eg. Oxygen you breathe today may have been in Texas a few days ago.

Clicker Question

Which are older, the *atoms* in the body of your grandmother or those in a new-born baby?

A) Those of your grandmother

B) Those in a new-born baby

C) They are the same age

Clicker Question

Which are older, the *atoms* in the body of your grandmother or those in a new-born baby?

A) Those of your grandmother

B) Those in a new-born baby

C) They are the same age

Answer: C

They are the same age – most of them nearly that of the universe, as that is when the atoms formed.

Another question

The average speed of a perfume vapor molecule at room temperature may be about 300 m/s, but the speed at which the scent drifts across the room is much less. Why?

Another question

The average speed of a perfume vapor molecule at room temperature may be about 300 m/s, but the speed at which the scent drifts across the room is much less. Why?

Although the molecular speed between collisions is great, the rate of migration in a particular direction, i.e. diffusion, is much less because of collisions between molecules and their random direction.

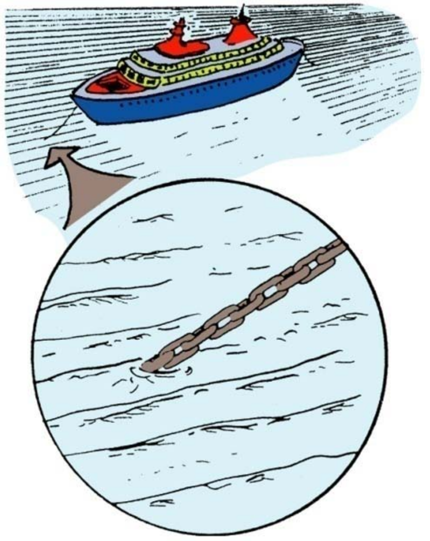
Atomic Imagery

- How to view atoms?

Actually, first, how do we view anything?

With visible light: Light is waves, that may bend around, reflect, bend through the object.

Analogy with water waves giving info about a ship:



Distance between crests of waves is the "*wavelength"* – ship is much bigger than this. Info about size and shape of ship is revealed by pattern of crests.

But if look at rope here, water waves can't detect (no change in their pattern) since rope too small.

- **So, can we see atoms with visible light?**

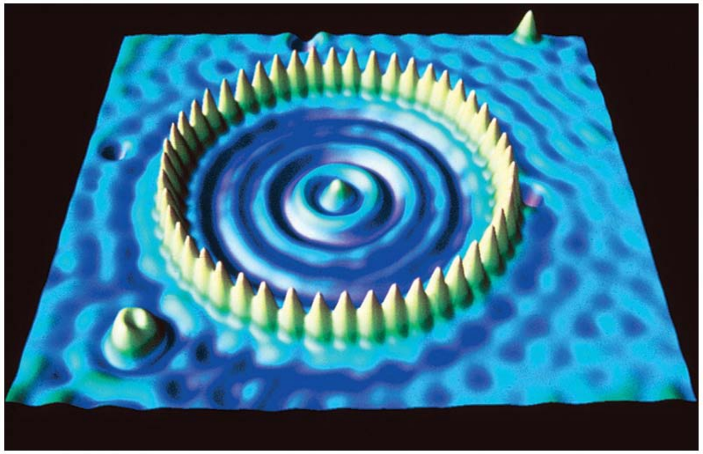
No, because the wavelength of light is larger than atoms – atoms are too small to influence the light wave patterns.

- Instead, use **electron beams** to view atoms - a stream of negatively charged particles that have wave properties

- First “picture” was in 1970, of thorium atoms

- Now, use **scanning tunneling microscope** (STM) – sharp tip scanned over surface, a few atomic diameters away. At each point, a tiny electron current is measured between the tip and surface and reveals the surface structure.

Eg. Here, a ring of 48 iron atoms on a copper crystal surface – ripples show wave nature of electrons.



Subatomic particles: (1) Electron

- **Brief history:** *(not examinable)*
  - **BC Greeks**, found when amber is rubbed, it attracted bits of straw. Electron is Greek for “amber”
  - **Ben Franklin** postulated idea of “electric fluid” : If matter has excess electric fluid, it is “positively charged” and if it is deficient, it is “negatively charged”.

    The fluid repels itself but attracts other objects.

  -- **Crooke’s tube 1870’s**: precurser of neon signs and cathode ray tubes (like in your tv/computer screen). Apply large voltage (battery) across electrodes in a tube with gas in it -- gas glows due to a “ray” coming from the negative terminal – called cathode. Ray is deflected by magnets, or charged objects.

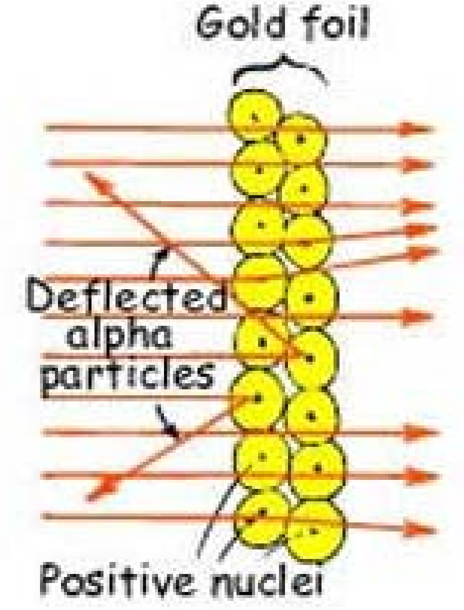
  -- **J.J. Thomson (1897)** – showed the cathode rays were particles, smaller than atoms, all identical. Showed ray’s deflection depended on particle’s mass, charge and speed. Soon after, named “electron”. Nobel Prize 1906.

  -- **Millikan (1900’s) –** oil drop experiment to determine numerical value of electron’s charge. Balancing gravity on the charged oil drop with electric force from electric field.

  Also deduced electron mass as 1/2000 that of hydrogen atom. Nobel Prize 1923.

- <u>Electrons in atoms – what is the structure of atom? Brief history</u>

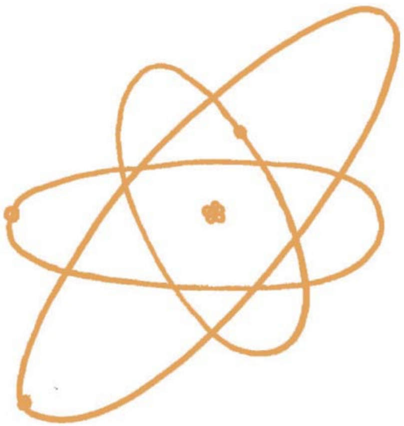
- **J.J. Thomson**: “plum pudding” model where electrons were like plums in a sea of positively charged pudding.
- **Rutherford** (early 1900’s): showed atom was mostly *empty space*, with mass concentrated in central **atomic nucleus**.
- His experiment: beam alpha particles (positive charge) into a very thin gold foil. Found most are undeflected (so deduced mostly empty space), and those that aren’t appear to hit something relatively massive and concentrated (so deduced existence of nucleus):



So, atoms are mostly empty space:

- A central, extremely dense nucleus surrounded by a cloud of buzzing electrons – actually the “orbiting” electron picture is not very accurate; the cloud picture is better. (Really need ***quantum mechanics*** to describe)

- Atom’s diameter = 10 000 x nucleus diameter !!



- Atoms are mostly empty space means that everything is mostly empty space. But atoms cannot pass through one another because of **electrical repulsion**: as two atoms approach, first their electron clouds get close, and so repel each other.

When you touch something, your nuclei do *not* touch; rather it is the electrical repulsion forces you feel.

- Nucleus contains almost all the atom’s mass, very dense. Nuclei are positively charged: if somehow strip atoms of electrons and let nuclei approach, they will repel each other. *Thermonuclear fusion* overcomes these very strong forces, squashing nuclei together..(eg in stars)

Clicker Question

The reason a granite block is mostly empty space is that the atoms in the granite are

A) not as close together as they could be.

B) invisible.

C) mostly empty space themselves.

D) held together by electrical forces.

E) in perpetual motion.

Clicker Question

The reason a granite block is mostly empty space is that the atoms in the granite are

A) not as close together as they could be.

B) invisible.

C) mostly empty space themselves.

D) held together by electrical forces.

E) in perpetual motion.

Answer: C

Subatomic Particles (2): Proton

- Positively charged protons live in the nucleus.

- In atom, same # of protons as electrons – atoms are electrically neutral.

- One proton has equal and opposite charge to one electron.
- A proton has mass ~ 2000 times that of electron

- Element is characterized/classified by the # of protons - called **atomic number**.

- eg all H atoms have one proton, all helium (He) atoms have 2, all lithium (Li) atoms have 3…So atomic #'s are 1, 2, and 3 respectively.

(note, have same # of electrons, 1 for H, 2 for He, 3 for Li)

- Atomic number orders elements in *periodic table* – see shortly.

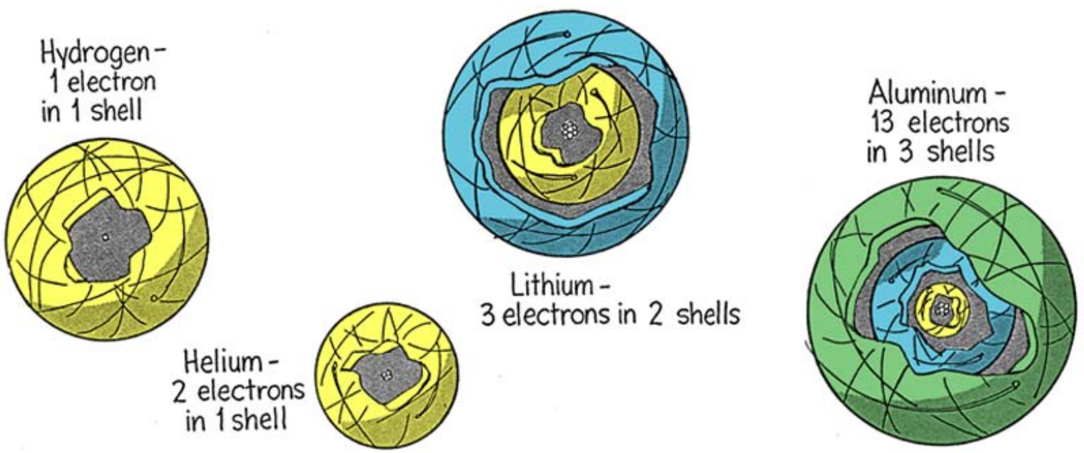
Shell model:

- Electrons in “concentric **shells**” around nucleus.

  1st shell can have up to 2 electrons,

  2nd shell “ “ “ “ 8 electrons

  7th shell “ “ “ “ 32 electrons..



The greater the number of protons in the nucleus, the more tightly bound are the electrons (smaller corresponding shells)

The shell structure (ie how electrons arranged) determines properties of the element eg melting temp, electrical conductivity, color, texture, taste…

Simplified....Even today, quantum chemists and atomic theorists research electronic structure to get more accurate description of electrons in atoms…

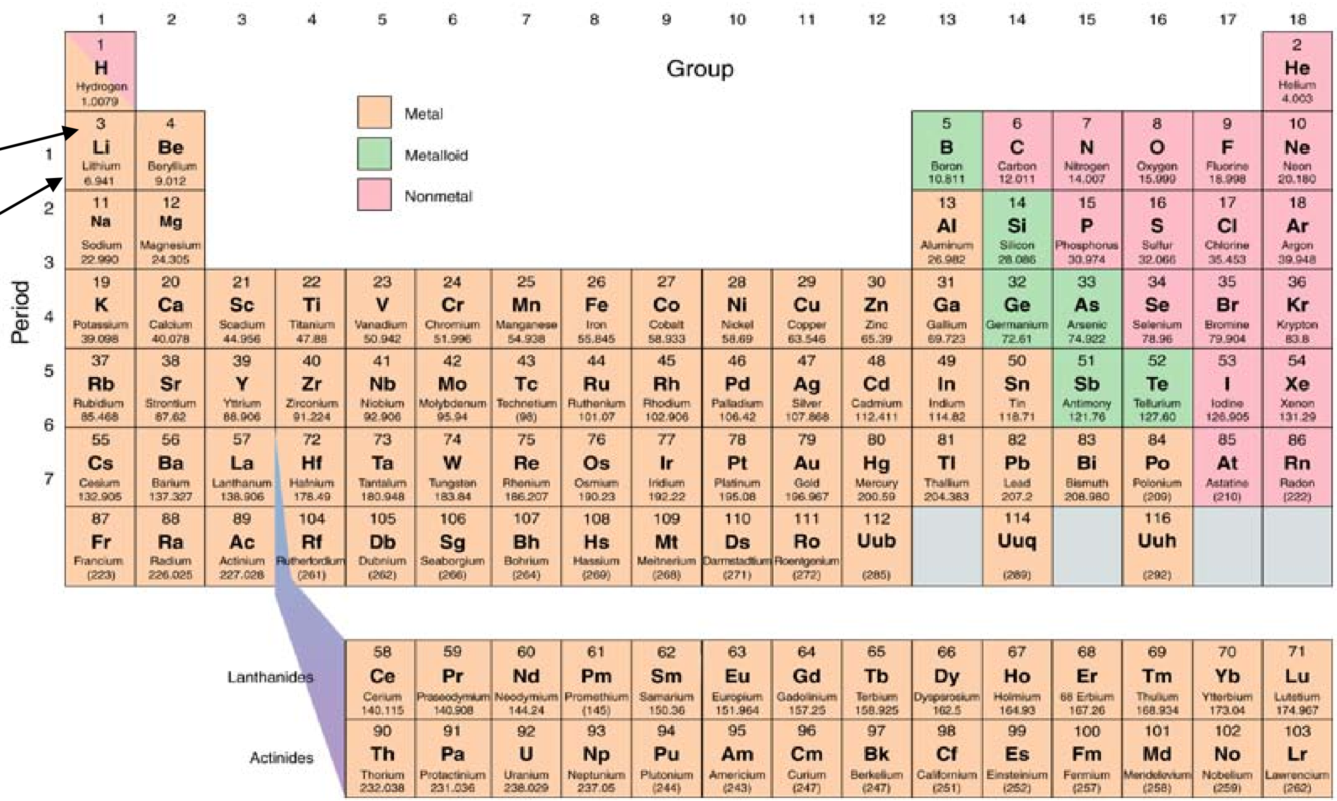
Periodic Table

- Arrange elements according to atomic number.
- From left to right, each element has one more proton and electron than the one before
- From top down, each element has one more shell than one above.
- All inner shells filled, outer shells partly empty except for the last column

Atomic number

Average atomic mass number

(see shortly)



“Noble gas” atoms, unreactive

Question

Oops!! Those harmless germanium tablets he just swallowed may have an extra proton in each nucleus.

Why should he be scared??

(refer to the periodic table)

Question

Oops!! Those harmless germanium tablets he just swallowed may have an extra proton in each nucleus.

Why should he be scared??

(refer to the periodic table)

Because, from the periodic table, adding one proton to germanium makes it arsenic !!

http://physics.wku.edu/~womble/phys260/millikan.html

Subatomic Particles: (3) The Neutron

- Uncharged particles in the neutron, with mass ~ that of proton.

- The # of neutrons need not match # of protons in atom, eg. H typically has 1 proton and 0 neutrons, but some H atoms may have 1 neutron, but always 1 proton, (called "heavy hydrogen")

- **Isotopes** = atoms of same element that contain different #'s of neutrons. *(Always same # of electrons and protons though)*

- **Atomic mass** = sum of masses of all components (p, n, e) minus small amount of mass that was converted to energy ("binding energy").

- Proton weighs 1.67 x 10^{-27} kg → kg is not a very convenient unit. Instead, define **atomic mass unit (amu),** where mass of proton ~ 1amu. (actually precisely defined through carbon-12…)

- **Atomic mass number =** sum of protons and neutrons

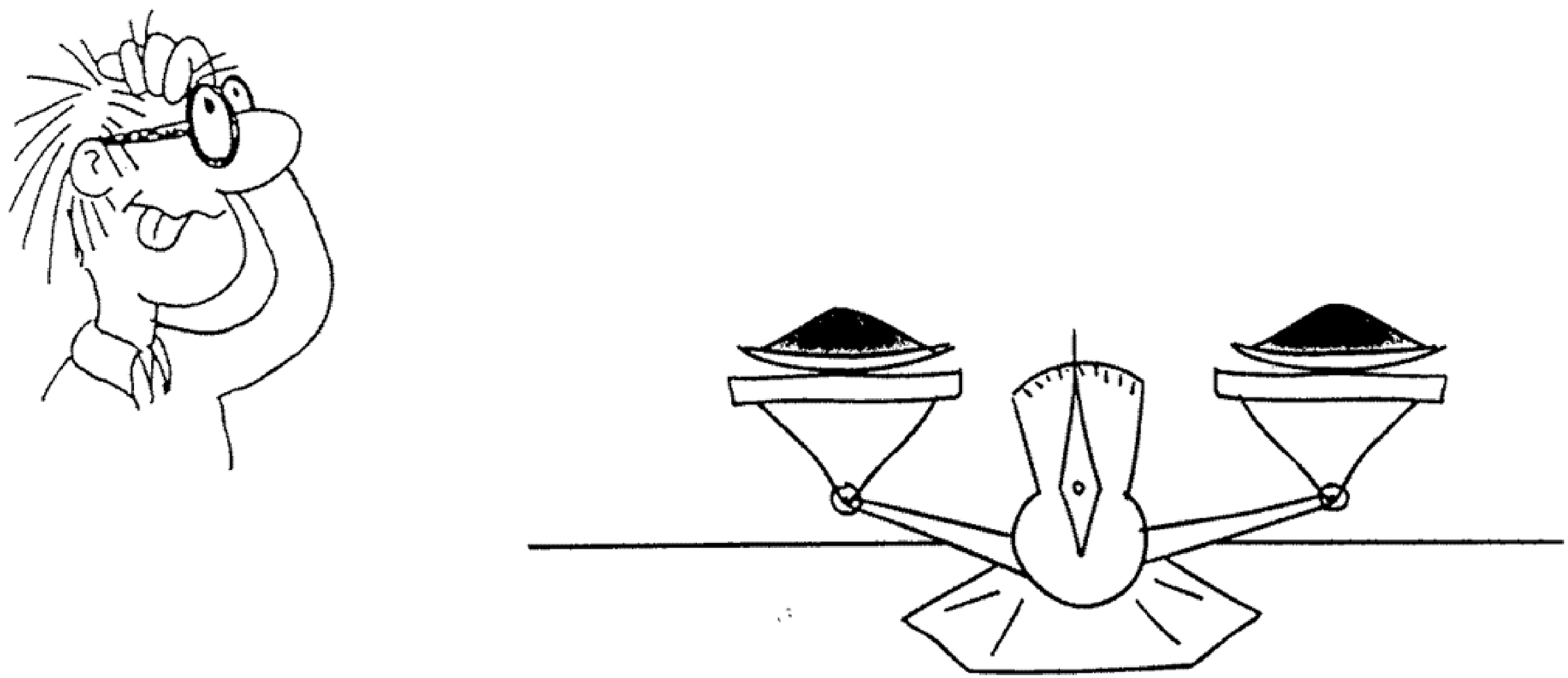
Eg. Most carbon has 6 protons and 6 neutrons, so atomic mass number is 12 amu.

About 1% of all carbon atoms has 7 neutrons, so atomic mass number of 13 amu. Called Carbon-13 (as opposed to carbon-12)

Average atomic mass of carbon is 12.011amu (in the periodic table)

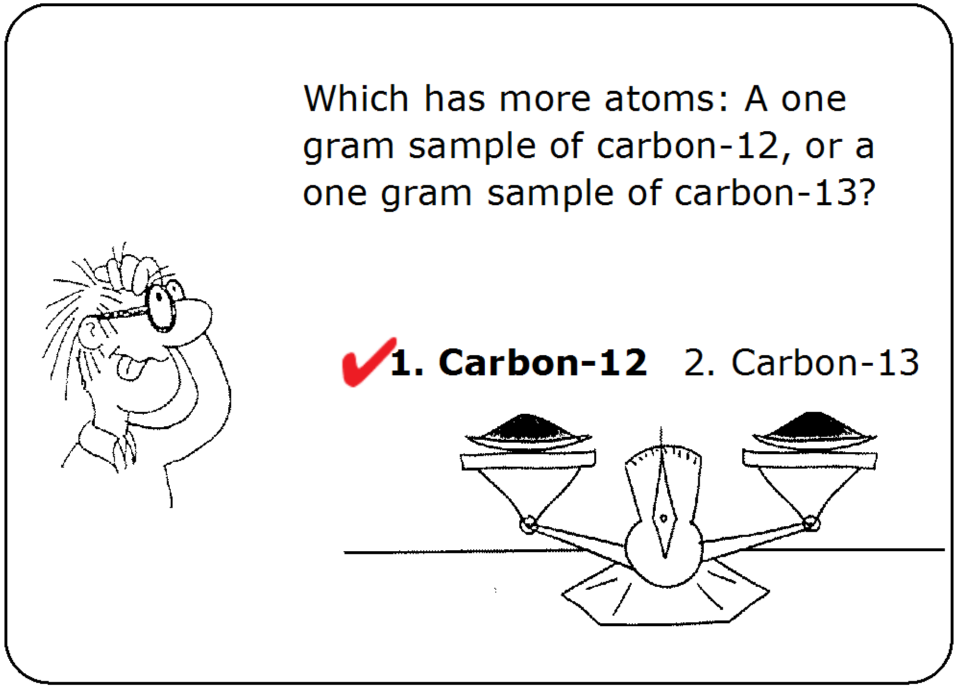
Clicker Question

Which has more atoms: A one gram sample of carbon-12, or a one gram sample of carbon-13?



A. Carbon-12 B. Carbon-13 C) Same # of atoms

Answer: A) Carbon-12



Think of it this way: If you had a pound of Ping-Pong balls in one bag and a pound of golf balls in another, in which bag would you have more balls? Because each golf ball weighs more, there are fewer of them in one pound. Similarly, the carbon-13 isotopes weigh more than the carbon-12 isotopes. So for equal masses of carbon-12 and carbon-13, there are more carbon-12 atoms in the carbon-12 sample.

Quarks

- In fact, even protons (p) and neutrons (n) are not indivisible – the fundamental ("elementary") particles are called **quarks** (1963). (Electron is also an elementary particle)

- Six different types but in p and n, just two types, "up" and "down". (Others called "top", "bottom", "charm" and "strange")

- A proton is composed of 3 quarks: 2 up, 1 down

  A neutron "   "   " 3 quarks: 1 up, and 2 downs.

- Quarks never exist alone! Only in "composite" particles like protons, neutrons. Existence deduced from eg. electron-proton scattering expts.

- Superstring theory: young field under intense research! Quarks are made of tiny vibrating loops…
- (Other elementary particles (meaning with no substructure) you may have heard of: electrons, neutrinos, Higgs boson…)

Elements vs compounds vs mixtures

Composed of a single kind of atom, eg. H, He

Made of elts that are chemically combined, ie bonds formed -- electrons shared across atoms

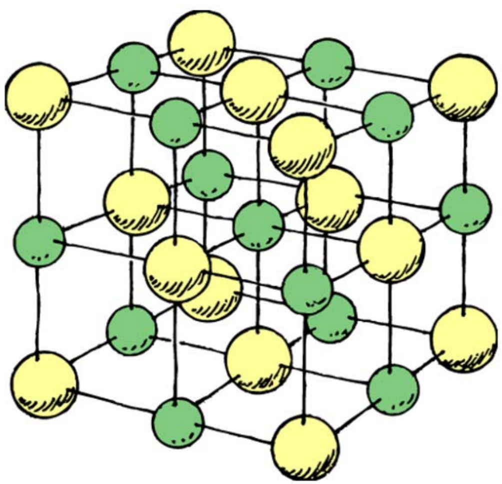
Eg. Water (H_20), salt (NaCl)

Very different properties than constituent atoms

Substances mixed together without being chemically combined,

Eg. Air (mostly N_2 and O_2)

Eg. NaCl - compound

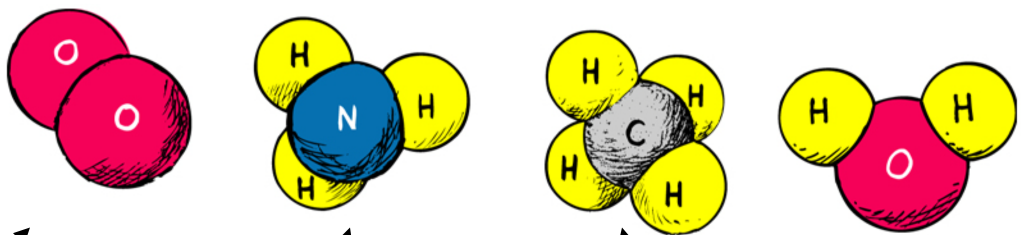


Many compounds are composed of **molecules –** next slide…

Molecules

- Smallest unit of a substance consisting of 2 or more atoms held together by mutual "sharing" of electrons; very well-defined bonding.

Eg:



oxygen (O_2) ammonia (NH_3) methane (CH_4) water (H_20)

- Changing one atom in a molecule can make a huge difference – eg chlorophyll in plants and hemoglobin in our blood *only* differ in the central atom (magnesium vs iron)

- **Chemical reaction** – when atoms rearrange to form different molecules.

Some chemical reactions…

- To pull molecules apart into constituent atoms, **need energy**. (c.f. pulling magnets apart).

Carbon dioxide

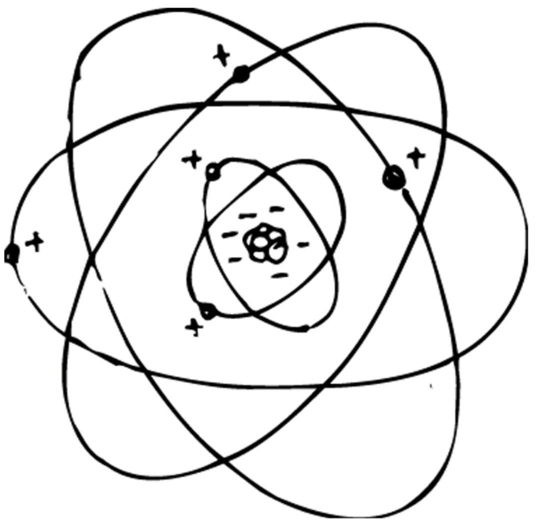
Eg. In photosynthesis, CO_2 in air is broken apart to C and O; energy provided by sunlight. This energy is stored in the carbohydrate molecules of the tree.

Combustion: when wood, or fuel, is **oxidized** – ie. C combined with O, releasing CO_2 and energy. Occurs slowly in digestion, fast in flames. If very fast, CO (carbon monoxide) also produced.

Other things oxidize, or “burn” – eg rusting of iron.

Antimatter

- Composed of atoms with **negative nuclei** and **positive electrons** (called **positrons**)



Positrons: (1932), first discovered in cosmic rays bombarding earth. Same mass as electron, equal but opposite charge.

Antiprotons: same mass as proton, equal but opposite charge.

Antiparticles: now made in labs with nuclear reactors. The first anti-atom (anti-hydrogen) made in 1995.

Every particle has an antiparticle – every quark has an antiquark.

Antiparticles of neutral particles like neutron have same mass, but different other properties (eg spin..we're not getting into this…)

More on antimatter

- If a particle meets an antiparticle, they completely annihilate each other – yielding radiant energy.

- Can’t get both matter and antimatter near each other for long. Strong reasons to believe in our part of the universe, we have only normal matter (no antimatter).

- The Large Hadron Collider: one question it’s supposed to answer is why universe is made up largely of matter rather than largely of antimatter.

(Another is to try to observe the Higgs boson, an elementary particle postulated to exist via which other elementary particles attain mass)

Clicker Question

A movie-maker runs this idea by you – that if an antimatter alien set foot upon the earth, the whole world would explode into pure radiant energy. What would you say?

A) Great idea!
B) No, the amount of matter annihilated would only have the mass of the alien, a pair of particles at a time.
C) No, the alien would survive but generate energy through interactions with humans.

Clicker Question

A movie-maker runs this idea by you – that if an antimatter alien set foot upon the earth, the whole world would explode into pure radiant energy. What would you say?

A) Great idea!
B) No, the amount of matter annihilated would only have the mass of the alien, a pair of particles at a time.
C) No, the alien would survive but generate energy through interactions with humans.

Answer: B

The amount of matter annihilated would be the same as the amount of antimatter, a pair of particles at a time. The whole world could only be annihilated if the mass of the alien were at least equal to the mass of the earth.

Dark Matter

- Light emitted from stars contains info about the elements inside them – stars and other bodies out in universe contain same particles we have on earth.

- But there is a lot more mass out there in the universe than we can see – called **dark matter** – pulls on stars and galaxies that we can see.

- Deduced gravitational forces in galaxies are far greater than what visible matter can account for.

- Estimated to be 90% of mass of universe!